
ENSO and Disaster: Droughts, Floods and El Niño/Southern Oscillation Warm Events

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The connection between El Niño/Southern Oscillation (ENSO) events and precipitation and temperature variability worldwide is increasingly well understood. ENSO has been linked to droughts and flooding in some regions. This paper uses the disaster history database of the U.S. Agency for International Development's Office of U.S. Foreign Disaster Assistance to examine the link between ENSO events and droughts or floods of sufficient magnitude to trigger international disasters. Worldwide, disasters triggered by droughts are twice as frequent during year two of ENSO warm events than during other years. No such relationship is apparent in the case of flood disasters. Drought disasters occur during year two of ENSO warm events significantly more frequently than in other years in Southern Africa and Southeast Asia. No regional pattern emerges from a comparable analysis of flood disasters. Those places likely to be affected by ENSO-triggered droughts can take proactive measures to mitigate the impacts.

Complex, conflict-related disasters in such places as Rwanda, Somalia and Bosnia capture the world's attention and absorb the majority of international humanitarian assistance. While natural disasters may have receded somewhat from the media headlines, events such as the eruption of Mt. Pinatubo in the Philippines and Southern California floods and Hurricane Andrew in the United States remind us that natural disasters with major human and economic impacts continue to occur. Fortunately, our ability to predict these events and take action to prevent, mitigate or prepare for their impacts is growing.

This paper relates El Niño/Southern Oscillation (ENSO) warm events to worldwide drought and flood disasters. El Niño

was the name originally given by fishermen to a localized warm current that appears several times per decade during the Northern Hemisphere winter off the Pacific coast of Ecuador and Peru. Today it is known that El Niño is a local manifestation of a much larger ocean/atmosphere system spanning the Pacific basin. The scale of this system is such that its oscillations perturb atmospheric circulation worldwide, through what are known as 'teleconnections', with pronounced regional effects on temperature and precipitation (Figure 1). Consequently, droughts and flooding tend to concentrate in teleconnected regions during ENSO warm-event years (Robinson and Ely, 1987).

While ENSO's connection to droughts

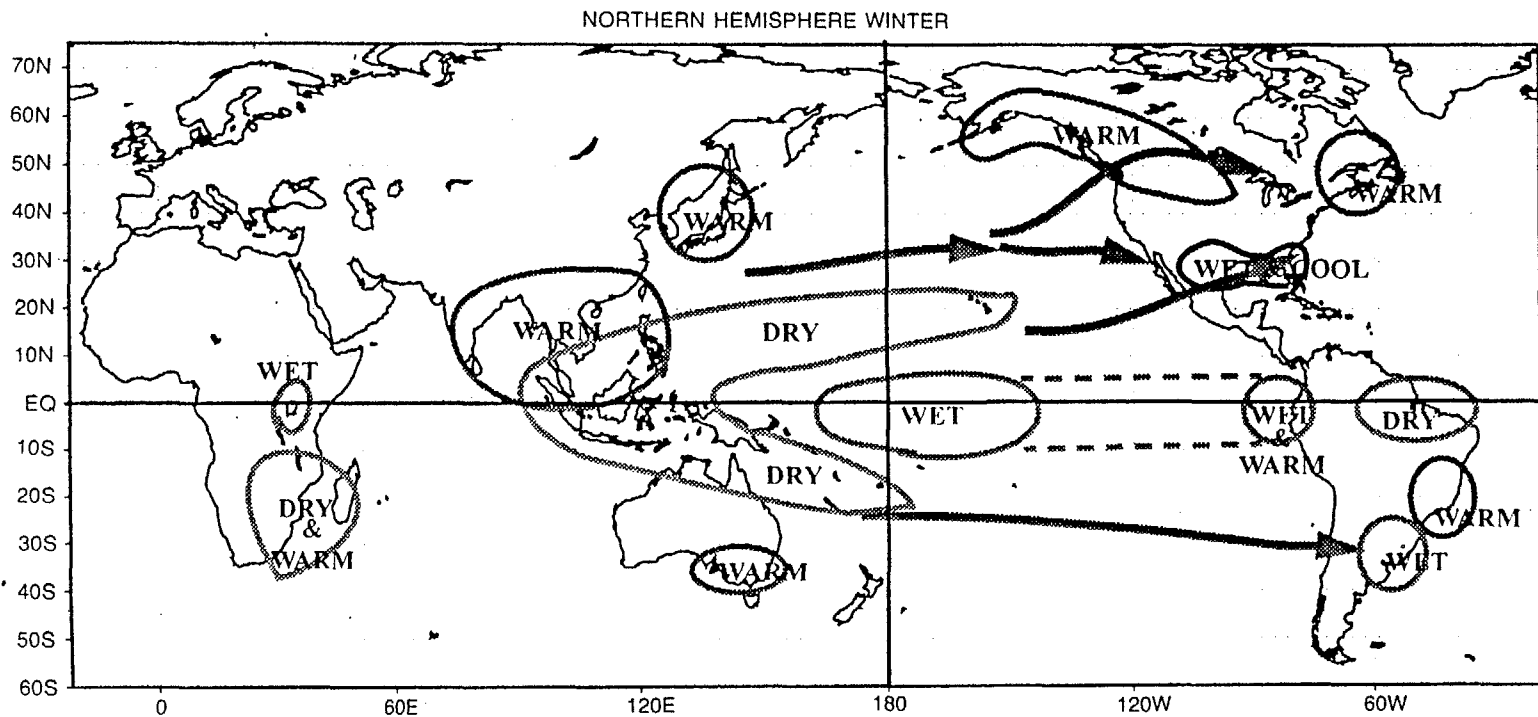


FIGURE 1 Warm (ENSO) episode-related temperature and precipitation anomalies during the Northern hemisphere winter. Heavy arrows represent the positions of strongest winds (jet streams) at high levels (30,000 to 35,000 feet) of the atmosphere (National Oceanic and Atmospheric Administration, based on Ropelewski and Halpert, 1987; Halpert and Ropelewski, 1992)

and floods is now recognized, the degree to which ENSO is linked to disasters has not been established. Droughts and floods are, on one level, hydro-meteorological events. Definitions of drought in particular, however, are often expanded to include agricultural or other socio-economic impacts (Wilhite and Glantz, 1985). In this sense, when the magnitude of the event is such that it causes social disruption exceeding an affected population's coping capacity, droughts and floods act as triggering events for disasters.

The human and financial costs of disasters triggered by droughts and floods are among the highest of all types of disasters. Worldwide, between 1967 and 1991 drought disasters killed 1.3 million people and affected 1.4 billion. Flood disasters killed 300 thousand people and affected 1.1 billion (IFRC 1993, pp. 103–105). Disasters exact high economic costs as well. In the Southern Africa drought disaster of 1991–92, which was associated with an ENSO warm event, the affected countries lost an estimated 3 million tons of grain production — food for 25 million people (IFAD, 1994). The estimated economic costs of the disaster — U.S. \$7 billion — equalled twenty times the level of World Bank lending to agriculture in all of Sub-Saharan Africa in the following year. The United Nations Development Program estimates that the costs of natural disasters to developing countries approximately equal official development assistance spending annually.

Recent advances in environmental monitoring and modelling allowed successful forecasts of ENSO warm events in 1986 and 1991 and have raised the possibility that ENSO events can be reliably predicted months, perhaps years, in advance (see Cane et al., 1986). To the extent that ENSO teleconnections cause regional droughts and flooding, such forecasts could warn of potential drought and flood disasters.

Early warning is an important component of disaster prevention, mitigation and preparedness. The United Nations International Decade for Natural Disaster Reduction promotes early warning systems as a means for reducing the need for post-disaster relief. Preventing disasters or reducing their impacts is a recognized and preferred approach to disaster response (see Cuny, 1983). The World Bank and U.S. Geological Survey calculate that a predicted \$400 billion in economic losses from natural disasters over the 1990s could be reduced by \$280 billion with a \$40 billion investment in prevention, mitigation and preparedness strategies. Such measures can be especially cost-effective when based on disaster early warnings, since the warning indicates circumstances where there is a high probability that a disaster will actually occur.

DATA

Information on worldwide disasters (excluding the United States) is maintained by the U.S. Agency for International Development's Office of U.S. Foreign Disaster Assistance (USAID, 1992). This database consists primarily of declared disasters in which the Chief of the U.S. Diplomatic Mission in the affected country determined that a U.S. government response was warranted. Some significant non-declared disasters are also included. Disaster data from 1964–1992 include 260 droughts in 73 countries and 556 floods in 110 countries. These disasters do not represent the totality of hydro-meteorological drought and flood events over that period, only those that triggered disasters and, in the case of declared disasters, an international response.

Seven ENSO warm events occurred during 12 of the 29 years in the study period: 1965, 1969, 1972–73, 1976–77, 1982–83, 1986–87, 1991–92 (Trenberth, 1991, p. 16). Major events occurred in

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1972–73, 1982–83, and 1991–92. Since ENSO warm events are a boreal winter-time phenomenon they generally span two years, maturing during February–April of the second year. Five years comprising ‘second years’ of ENSO warm events — 1973, 1977, 1983, 1987 and 1992 — were selected as ‘ENSO years’ for the purpose of analysis. By the second year, ENSO-related conditions had persisted over an extended period, with an accumulation of impacts.

METHODS

Two analyses were performed. The first, a *t*-test, compared the average frequencies of worldwide drought and flood disasters during ENSO versus non-ENSO years. The second identified individual countries whose disaster histories show statistical associations between drought or flood disasters and ENSO warm events using a χ^2 test. In this test, the 29 years in the study period were categorized as disaster or non-disaster, ENSO or non-ENSO in a contingency table. Disaster years were considered to be those in which one or more drought or flood disasters were recorded for the country in that year. The cross-tabulation of ENSOs with disasters was evaluated for its significance in each case. The χ^2 test identified those countries in which drought or flood disasters tended to occur during ENSO years but not in other years. This distinction is important in the disaster early warning application of ENSO forecasting since some countries have frequent droughts and floods regardless of whether or not an ENSO event occurs.

Some countries experience multiple disasters within a single year, particularly in the case of flooding. The characteristics of the normal distribution can be used to specify the probability that the proportion of disasters occurring during ENSO years

is due to random chance. If disasters were independent of ENSOs in a particular country one would expect the proportion of ENSO disasters to resemble that of ENSO years. On the other hand, if ENSOs occur during only a small proportion of the years, but a great majority of the disasters occur in ENSO years, it becomes more likely that disasters are not randomly distributed over the years but rather are related to ENSO events. If the *Z* score of the difference between the two proportions exceeds a specified level, the null hypothesis that there is no difference between them can be rejected at the corresponding level of confidence.

RESULTS

During year two of ENSO warm events drought disasters are twice as frequent worldwide as in other years (Figure 2). The average worldwide frequency of drought disasters during these years is 15.4, versus 8 during all other years, a significant difference at the 0.005 level. There is no significant difference in the average frequency of flood disasters during ENSO warm events versus other years (Figure 3).

From 1964–1992 in 19 countries there is an association between drought disasters and ENSO warm events during year two of the event (Table 1). The spatial distribution of these countries (Figure 4) corresponds to that of dry/warm ENSO teleconnections shown in Figure 1. The countries are concentrated in Southern Africa and Southeast Asia. Southern Africa has an ENSO teleconnection characterized by warm and dry conditions. Southeast Asia experiences warming, dryness or both during ENSO warm events.

In 13 countries flood disasters were associated with ENSO warm events during year two of the event (Table 2). In contrast to drought disasters, however,

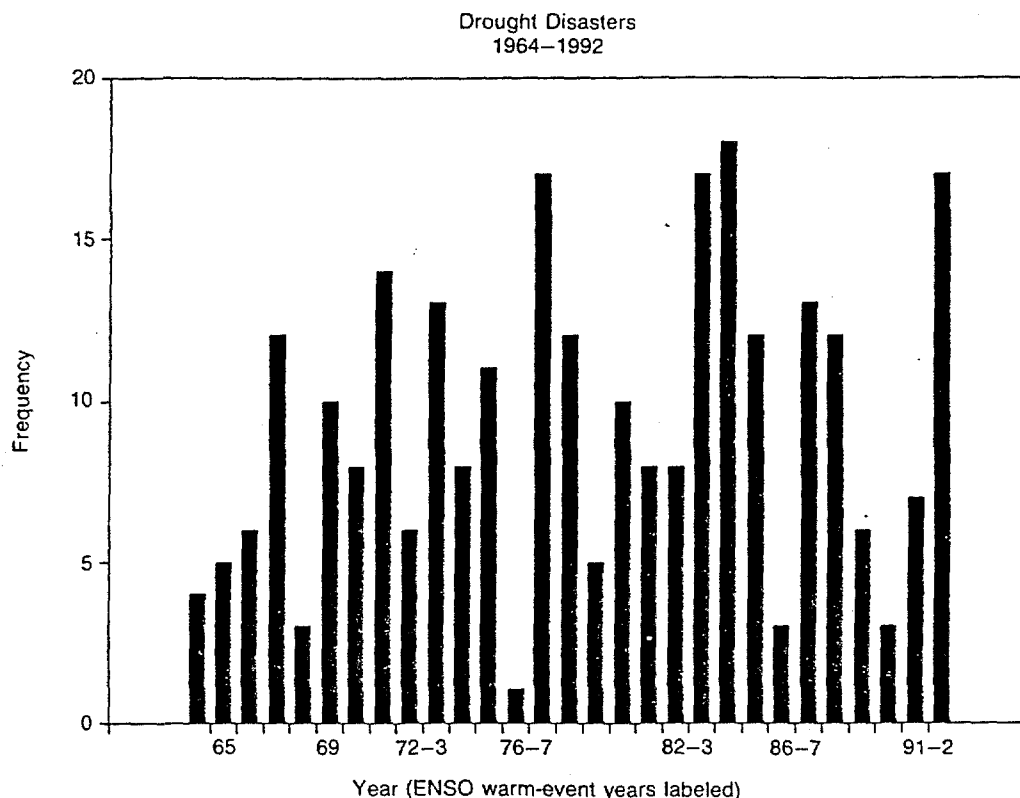


FIGURE 2 Worldwide drought disasters in relation to ENSO warm events

these countries are not grouped regionally according to any known spatial patterns of ENSO precipitation teleconnections (Figure 5). There is no clear hydro-meteorological link between flood disasters and ENSO warm-event teleconnections in these countries.

When all ENSO warm-event years are considered, rather than just year two, in the case of drought disasters only South Africa, Swaziland, and India show a statistically significant relationship between disasters and ENSOs at the 0.05 level as measured by χ^2 , with Chile, Malawi and the Philippines significant at the 0.1 level. Only one country, Senegal, exhibited a statistically significant relationship between flood disasters and ENSO warm events.

DISCUSSION

In contrast to flood disasters, there is a highly significant increase worldwide in the average number of drought disasters during year two of ENSO warm events compared with other years, based on a sample of 260 drought disasters over a 29 year period. The spatial distribution of the countries in which these disasters occur corresponds to that of dry/warm ENSO teleconnections. In individual countries showing statistically significant relationships between ENSO warm events and drought disasters, however, mainly in Southern Africa and Southeast Asia, occurrence of a warm event does not necessarily predict a disaster. In these countries, disasters typically occurred in

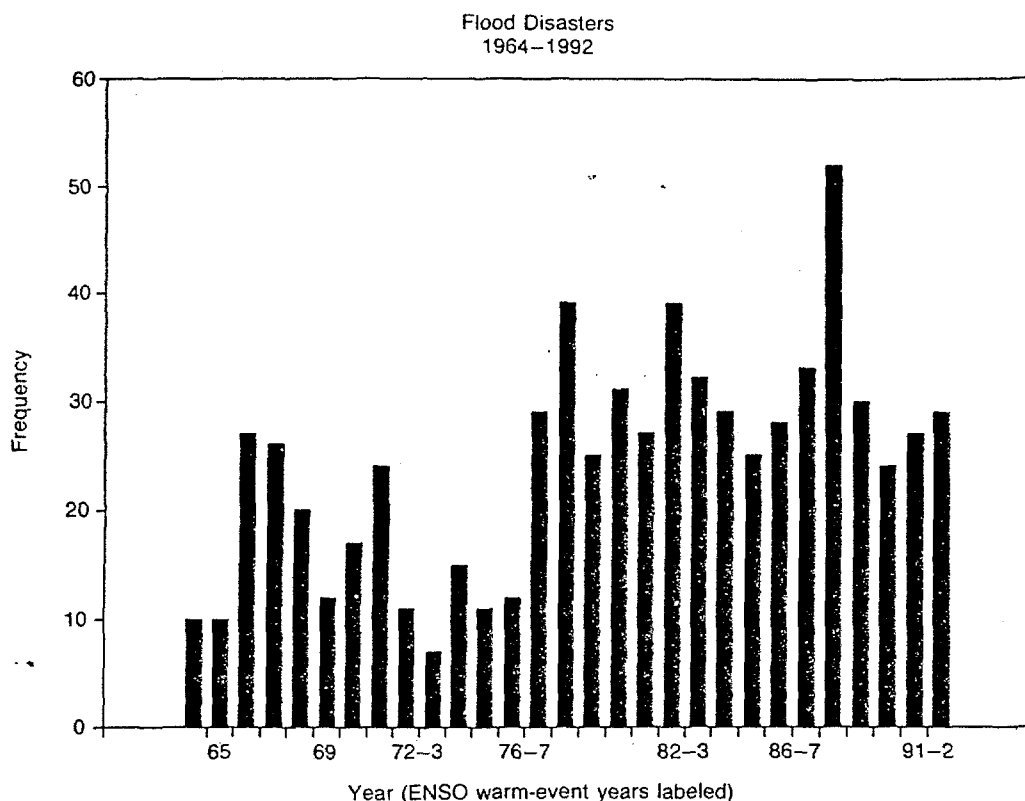


FIGURE 3 Worldwide flood disasters in relation to ENSO warm events

less than half of the selected ENSO events (Table 1). Thus, disasters do not automatically result from periods of reduced rainfall or even hydro-meteorologically defined droughts such as may be caused by ENSO warm events in these regions. Disasters are by definition extreme events that occur only when the magnitude of the triggering event has been sufficient to overwhelm the coping capacity of the affected population. Nevertheless, all countries affected by ENSO teleconnections need to consider potential ENSO impacts. The sharp increase in drought disasters worldwide in the mature stage of multi-year ENSO events means that more countries are affected during these events than at other times.

Climate variations due to ENSOs can

have agricultural or hydrological effects leading to substantial economic loss and popular suffering, even while remaining at sub-disaster levels. A growing body of literature documents the socio-economic impacts of ENSO teleconnections throughout the world. Rainfall variations associated with ENSO in Zimbabwe, for example, have been shown to be strongly associated with variations in agricultural production (Cane et al., 1994). Impacts of ENSO teleconnections in Australasia reviewed by Allan (1991) include those on cereal crops in Australia, low or late monsoon rainfall from Indonesia east to New Guinea, and population fluctuations among diverse marine resources. ENSO effects on fisheries in the eastern Pacific have been documented by Glantz (1985).

TABLE 1
Statistical relationships between drought disasters and ENSO warm events in 1973, 1977, 1983, 1987 and 1992 (the second years of two-year events) from 1964 to 1992 for selected countries¹

Country	Years in which disasters were declared				All disaster events			
	χ^2	Number of drought disaster years	% of disaster years falling in Year 2 of ENSO warm events	% of ENSO warm events (Year 2) experiencing drought disasters	Z	Number of drought disaster events	% of disaster events in Year 2 of ENSO warm events	Years with drought disasters and ENSO warm events (Year 2)
Philippines	10.31	2	100	40	2.71	2	100	83 87
Cambodia	4.97	1	100	20	2.03	1	100	87
Cape Verde Is.	4.97	1	100	20	2.03	1	100	92
Costa Rica	4.97	1	100	20	2.03	1	100	73
Fiji	4.97	1	100	20	2.03	1	100	83
Japan	4.97	1	100	20	2.03	1	100	77
Namibia	4.97	1	100	20	2.03	1	100	92
Rwanda	4.97	1	100	20	2.03	1	100	77
Tibet	4.97	1	100	20	2.03	1	100	83
Vietnam	4.97	1	100	20	2.03	1	100	87
Zambia	4.97	1	100	20	2.03	1	100	92
South Africa	5.73	3	67	40	1.97	3	67	83 92
Swaziland	5.73	3	67	40	1.97	3	67	83 92
Laos	3.49	4	50	40	1.50	4	50	77 87
Sudan	3.49	4	50	40	1.50	4	50	83 92
Tanzania	3.49	4	50	40	1.50	4	50	77 92
Sri Lanka	4.42	7	43	60	1.46	7	43	77 83 87
Indonesia	1.37	6	33	40	1.46	7	43	73 87 87
India	4.24	7	43	60	1.23	8	38	73 83 87

¹ Countries shown have χ^2 or Z value significant at 0.1 or higher.

For 1 Degree of Freedom:

Level	χ^2	Z
0.200	1.642	
0.100	2.706	1.28
0.050	3.841	1.65
0.020	5.412	
0.010	6.635	2.33
0.001	10.827	

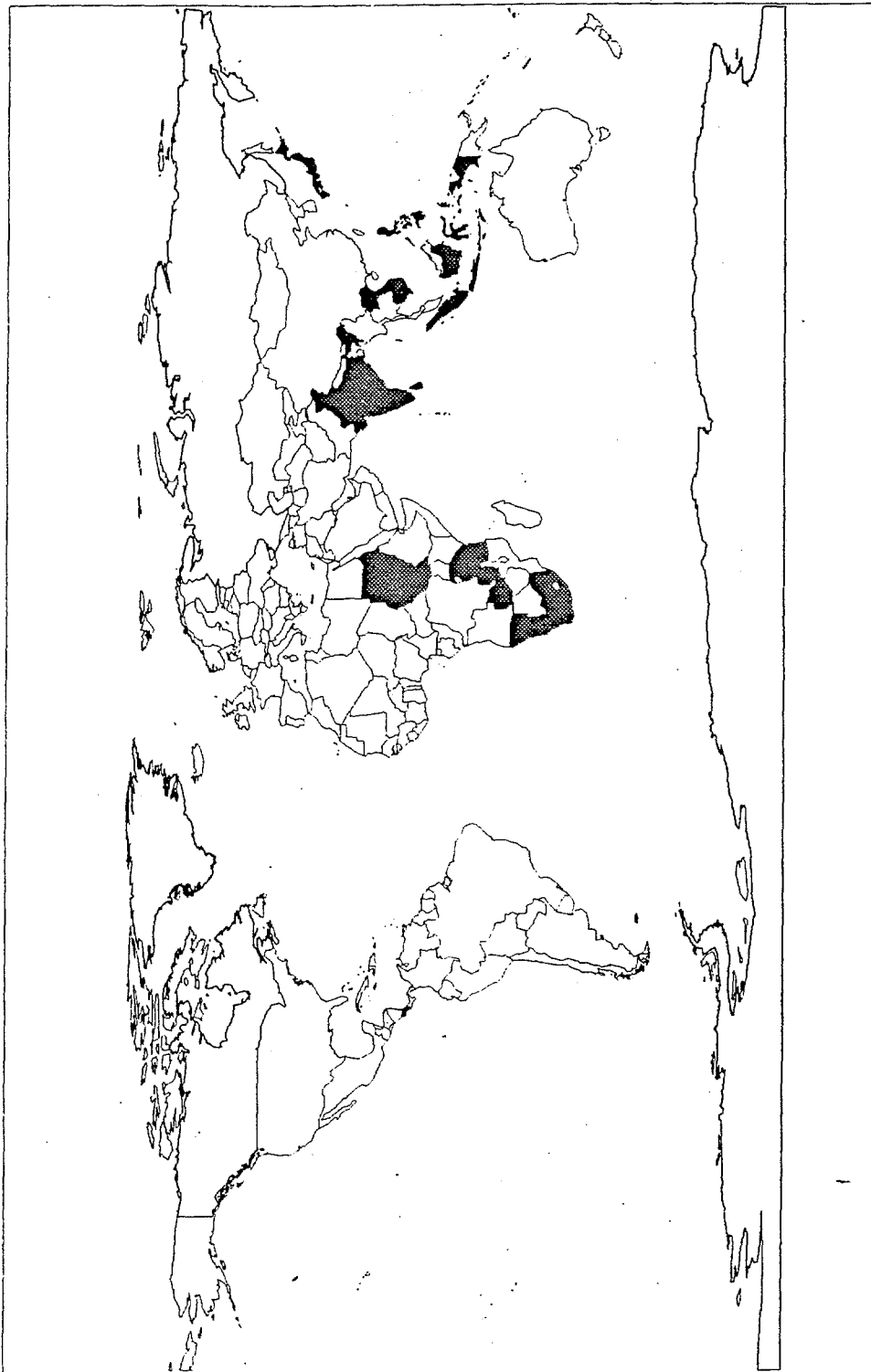


FIGURE 4 Countries where drought disasters are significantly more frequent during year two of ENSO warm events than in other years

TABLE 2
Statistical relationships between flood disasters and ENSO warm events in 1973, 1977, 1983, 1987 and 1992 (the second years of two-year events) from 1964 to 1992 for selected countries²

Country	Years in which disasters were declared				All disaster events			
	χ^2	Number of flood disaster years	% of disaster years falling in Year 2 of ENSO warm events	% of ENSO warm events (Year 2) experiencing flood disasters	Z	Number of flood disaster events	% of disaster events in Year 2 of ENSO warm events	Years with flood disasters and ENSO warm events (Year 2)
France	5.73	3	67	40	2.53	4	75	77 83 83
Cuba	7.74	5	60	60	2.08	5	60	77 83 92
Czechoslovakia	4.97	1	100	20	2.03	1	100	87
Lebanon	4.97	1	100	20	2.03	1	100	87
Madagascar	4.97	1	100	20	2.03	1	100	87
Maldives	4.97	1	100	20	2.03	1	100	87
Papua New Guinea	4.97	1	100	20	2.03	1	100	83
St. Kitts	4.97	1	100	20	2.03	1	100	87
Sweden	4.97	1	100	20	2.03	1	100	77
Tajikistan	4.97	1	100	20	2.03	1	100	92
China, Rep. of	1.62	2	50	20	1.97	3	67	77 77
Guatemala	3.49	4	50	40	1.50	4	50	73 87
Poland	3.49	4	50	40	1.50	4	50	77 87

² Countries shown have χ^2 or Z value significant at 0.1 or higher.

For 1 Degree of Freedom:

Level	χ^2	Z
0.200	1.642	
0.100	2.706	1.28
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0.001	10.827	

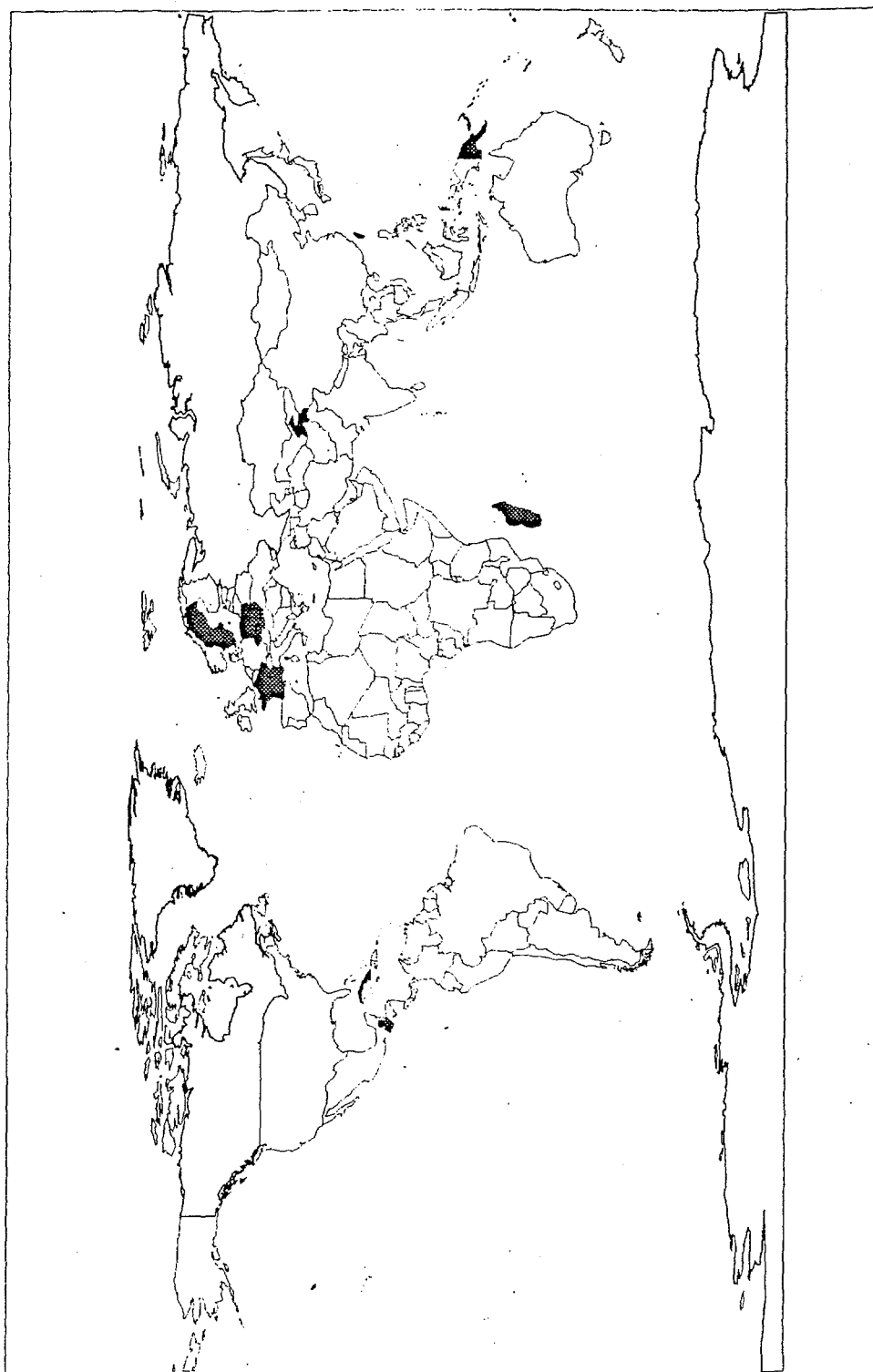


FIGURE 5 Countries where flood disasters are significantly more frequent during year two of ENSO warm events than in other years

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In the Valley of Oaxaca, Mexico, local rainfall correlates highly with rain-fed maize yields but its spatial variability is such that the annual average value of the Southern Oscillation Index¹ is actually a better regional yield predictor (Dilley, in preparation). These and similar results suggest that ENSO forecasts can provide valuable information for both disaster preparedness and development planning.

Successful use of ENSO forecast information depends on establishing a series of linkages between climatologists, planners, policy-makers and policy-implementors. Climatologists, particularly those working in countries affected by ENSO, must understand the mechanisms through which ENSO teleconnections affect regional and local climates. Teleconnections are modulated by other synoptic controls which can greatly influence the behavior of local and regional climate during ENSO events. By monitoring ENSO onsets and providing regionally or locally tailored forecasts, climatologists can provide early warning of disasters or other socio-economically important impacts. At the planning level, appropriate policies, keyed to the local climatic conditions associated with ENSO, can contribute to prevention and mitigation of, or preparedness for, adverse ENSO impacts. Impacts are a function of the magnitude of the event as well as the sensitivity or vulnerability of the affected population. Therefore, the nature and causes of societal vulnerability to climatic variations must be understood before it can be reduced. Finally, institutions need to implement relevant policies, work towards reducing long-term vulnerability and promote effective shorter term disaster prevention, mitigation and preparedness actions when ENSO events are forecast. To maintain such institutions, developing countries that are prone to drought disasters or other adverse impacts during extended ENSOs may require support

from donor governments.

ENSO information is already being used for planning in some drought-prone countries. In Australia, the Queensland Department of Primary Industries and the Bureau of Meteorology advise farmers on livestock stocking rates, disease and parasite control, crop selection and planting times based on ENSO information (Partridge, 1991). In northeastern Brazil in 1991, government officials successfully used knowledge of the impending ENSO event to advise farmers on crop varieties and planting dates. By instituting water conservation strategies as well, they successfully maintained crop yields at near-average levels throughout an extended drought (Miller, 1994). Ethiopian National Meteorological Service Agency (NMSA) forecasters report that government decision makers are using long-range forecasts based on ENSO information to recommend agricultural strategies that maximize the benefits of forecasted rains and minimize losses from forecasted droughts (Nicholls and Katz, 1991).

SUMMARY AND CONCLUSIONS

Worldwide, drought disasters occur much more frequently during and following the mature phases (i.e. year two) of multi-year ENSO warm events than at other times, probably owing to prolonged, or successive, droughts accompanying the event in teleconnected areas. Drought disasters are associated with warm events in Southern Africa and Southeast Asia, regions where ENSO teleconnections are associated with anomalously dry and/or warm conditions. In contrast, flood disasters do not occur significantly more or less frequently worldwide during the mature phase of ENSO warm events. A dozen countries show propensities for flood disasters during the second year of two-year ENSO events but do not correspond spatially to

known ENSO teleconnections.

These findings suggest that countries with ENSO teleconnections favoring drought, particularly in Southern Africa and Southeast Asia, should take the possibility of drought disasters during ENSO events seriously. Advances in ENSO forecasting, plus the fact that drought disasters occur in the later phases of ENSO events, allow ENSO information to be used to warn of drought disasters a year or more in advance. This connection between drought disasters and ENSO events adds to a growing body of evidence linking ENSO to socio-economic impacts. Planners, decision-makers and farmers in tele-connected regions who recognize the propensities of their countries for precipitation fluctuations during ENSO years can take appropriate steps to limit adverse impacts.

The ability to predict ENSO events is an important element in natural disaster prediction. Successful predictions, when linked with the proper actions on the part of policy and decision makers, can help reduce the human and economic impact of disasters on vulnerable populations and advance the objectives of the United Nations International Decade for Natural Disaster Reduction.

Notes

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1. The Southern Oscillation Index is the sea-level pressure at Tahiti minus that at Darwin, Australia, and is commonly used to monitor ENSO.

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